Research Article

Evaluation of Growth Performance, Forage Yield, and Nutritive Value of Five Imported Leucaena (*Leucaena leucocephala* (Lam.) de Wit) Cultivars as Ruminant Feed in Vietnam

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Abstract | Leucaena foliage has been utilized as a protein-rich feed source for ruminants, particularly goats, to address feed shortages and nutritional imbalances in smallholder farms. This study evaluates the growth performance, forage biomass yield, and nutritive values of five leucaena cultivars: Tarramba, Peru, Cunningham, KU15, and KU56. These cultivars were imported from Thailand and grown in Central Vietnam, which features a tropical monsoon climate and low hilly acidic soil conditions. Data was collected from two harvests in the first year of planting. The experiment employed a randomized complete block design (RCBD) with four replications for each cultivar. Seedlings, aged three months at transplantation, were planted and harvested twice at six-month intervals. Results indicated that the Tarramba and KU56 cultivars exhibited superior growth performance, showing greater plant height and stem diameter compared to the Peru, Cunningham, and KU15 varieties. However, there were no differences in the number of branches among the cultivars. The biomass yield from the second harvest was greater than that from the first. Additionally, no notable differences were found in the chemical composition of crude protein (CP), ether extract (EE), neutral detergent fiber (NDF), acid detergent fiber (ADF), and total ash in the leaves and in-vitro digestibility of DM, NDF and ADF of the five cultivars. These findings suggest that all five Leucaena cultivars have comparable nutritive value and demonstrate potential as viable sources of crude protein for ruminant production on smallholder farms in Vietnam.

Keywords | Growth, Forage yield, Chemical composition, *In vitro* digestibility, Ruminants

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INTRODUCTION

Goat farming is an important livelihood activity for smallholders in developing countries, providing income, meat, and milk. However, productivity remains constrained by imbalanced nutrition and protein deficiencies, which reduce growth and animal performance (Tolera *et al*., 2000; Mohsan *et al*., 2019; Pirzado *et al*., 2016). In Vietnam, the demand for goat products has increased steadily, with the national herd expanding from 1.6 million in 2014 to 2.8 million in 2023 (Vietnam Livestock Statistics, 2024). This growth is primarily concentrated in the northern mountainous and central coastal regions, where smallholders manage 73.42% of goat farms (Vietnam Livestock Statistics, 2024). Production systems are gradually shifting from extensive grazing to intensive cut-and-carry systems. Despite this transition, natural forages remain the primary feed source because protein-rich commercial feeds are often unaffordable. In many areas, grasslands are limited or degraded, resulting in low nutritional quality and protein deficits that constrain goat productivity (Nguyen *et al*., 2023; Nam *et al*., 2023).

Vietnam was typically characterized by two distinct seasons: Dry and rainy. These seasonal variations lead to fluctuating temperatures, which contribute to seasonal forage scarcity and feed shortages, particularly for smallholder farms that do not have proper feed preservation systems. As a result, farmers are likely to face high feed costs, rely on imported sources, and become increasingly vulnerable to market fluctuations. Climate change further exacerbates these challenges by impacting the availability and quality of local forage resources, along with associated risks. Therefore, it is crucial to expand the use of locally adapted forage crops to improve feed availability and ensure a year-round supply of nutritious and affordable feed resources. This approach is essential for reducing input costs for farmers. Expanding and diversifying forage systems while considering the nutritional quality of diets is necessary for establishing a sustainable local feed supply.

Leucaena foliage has been widely used as a protein feed source in ruminant diets in many countries (Okoruwa, 2020; Álvarez Ríos *et al*., 2018; Takawale *et al*., 2016; Nakamanee *et al*., 2019). In Vietnam, leucaena is regarded as an effective protein supplement for livestock, particularly in times of feed shortages. This tropical plant thrives in warm climates and plays an important role in goat production systems (Cowley and Roschinsky, 2019). Due to its high protein content, leucaena is a valuable feed resource for animal husbandry in tropical and subtropical areas, helping to alleviate protein deficiencies in animal diets. In Vietnam, leucaena forage offers notable advantages compared to other protein supplements. This plant is widely cultivated in tropical regions and thrives in warm weather. It can grow well in various landscapes, including hilly areas, along home garden fences, and in different types of soil. Leucaena is capable of year-round regrowth (Casanova-Lugo *et al*., 2014), and farmers often use cut-and-carry methods to maximize its yield. By planting it once, they can harvest multiple times, ensuring a consistent feed supply at low investment costs. Although leucaena contains anti-nutritional factors such as mimosine (Bairagi *et al*., 2004), these can be effectively managed by including it in diets at levels below certain dietary thresholds (Wiyabot, 2022; De Angelis *et al*., 2021).

Leucaena is recognized as a valuable source of protein feed that can improve growth performance and enhance the quality of carcass meat (Casanova-Lugo *et al*., 2014; Wiyabot, 2022; Marhaeniyanto *et al*., 2023; Muinga *et al*., 1995). However, the nutritional responsiveness of newly introduced leucaena at different harvest times throughout the year has not been extensively studied. Understanding the growth performance, forage yield, and nutritional composition of leucaena cultivars is essential for feeding Vietnamese goats. This knowledge will help farmers make necessary adjustments to feed intake in response to changing weather conditions. Therefore, this study aims to evaluate the growth performance, biomass yield, and nutritional composition of selected leucaena cultivars. The findings will provide a solid background for improving goat feeding practices, ensuring a sustainable protein supply, and enhancing resilience in smallholder production systems.

MATERIALS AND METHODS

Plants

The cultivars of *Leucaena leucocephala* used in this study are *Leucaena leucocephala* Tarramba, *Leucaena leucocephala* Peru, *Leucaena leucocephala* Cunningham, *Leucaena leucocephala* KU15, and *Leucaena leucocephala* KU56. These leucaena seeds were imported from Kasetsart University in Bangkok, Thailand. Seeds from the five leucaena cultivars were sown in nursery pots, with one seed per pot. Sowing occurred on November 1, 2022, and the seedlings were nurtured in the nursery for three months before being transplanted to the experimental fields on February 1, 2023.

Field management: Soil uniformity and amendments

The experiment was conducted on the farm of the Institute for Development Studies, located in Huong Tra town, Hue city, Vietnam. The area covered approximately 1,000 square meters (34 m × 28 m) and was situated on flat ground in a hilly, non-flooded region. The soil was carefully weeded and thoroughly plowed. Five soil samples were collected at 4 locations in 4 angles and 1 location in the middle of the field. The soil samples were analyzed for pH, organic matter (OM), total nitrogen (N), total available phosphorus (P_2O_5), and total available potassium (K_2O) at the laboratory of Hue University of Agriculture and Forestry following standard soil analysis procedures. The methods and results of the baseline soil analysis are presented in Table 1. The soil pH values ranged from 4.75 to 4.95, with an average of 4.83. This indicates that the soils are slightly to moderately acidic. Such acidity levels are common in tropical humid regions and may limit nutrient availability. Organic matter content ranged from 2.45% to 2.67%, with an average of approximately 2.57%. This level is considered moderately good for plant growth. Total nitrogen content varied from 0.042% to 0.047%, with an average of around 0.045%.

Table 1: Chemical composition of the experimental soil.

Parameters	Methods	Values			Classification
		Mean	Min	Max	
pH_{KCl}	pH meter	4.83	4.75	4.95	Slightly acid
Organic (%)	Tyurin/ Tiurin	2.57	2.45	2.67	Average
N total (%)	Kjeldahl	0.045	0.042	0.047	Low
P_2O_5 total (%)	Spectrophotometer	0.021	0.020	0.023	Low
K_2O total (%)	Flame photometer	0.224	0.210	0.240	Average

This indicates a low to moderate nitrogen level. Available phosphorus ranged from 0.020% to 0.023%, with an average of approximately 0.021%. This level is considered low. Available potassium levels range from 0.21% to 0.24%, with an average of 0.224%. This is a moderately good level. Overall, the soil samples show moderate levels of organic matter and potassium, but low levels of pH, nitrogen, and phosphorus.

Soil amendments were applied to the baseline soil. Fertilizer NPK (15-15-15), organic manure and lime (CaO) were applied at a dose of 312.5 kg/ha, 10 tons/ha and 250 kg/ha, or 0.66 kg/plot, 21 kg/plot and 0.53 kg/plot, respectively. All plots received identical rates of lime and fertilizer. The soil assessment indicated uniformity, with no significant pre-existing heterogeneity among experimental plots.

Weather characteristics during the experiment

Central Vietnam experiences two distinct seasons: The dry season from March to August and the rainy season from September to February of the following year (Figure 3). During the six months of the dry season in 2023, the total rainfall was 334 mm, with an average of 55.7 mm per month, and the lowest amount was recorded in March at just 2.2 mm. In contrast, from September 2023 to February 2024, the total rainfall reached 4,203 mm, with an average of 700 mm per month, and the highest amount was seen in October at 1,627.6 mm.

The number of sunshine hours also varied between the two seasons, with 1,351 hours recorded during the dry season compared to 658.4 hours during the rainy season. The average annual temperature was 25.7 °C, with the lowest temperature occurring in January 2023 at 19 °C. Humidity levels fluctuated throughout the year, ranging from 75% in August to 93.5% in December 2023 (Figure 3).

Experimental design

The experiment was conducted using a randomized complete block design (RCBD), incorporating four replications of each variety. The distance between blocks and plots was set at 2.0 meters. Each plot measured 6.0 meters by 2.0 meters, with a total of 20 plots allocated in four blocks (Figure 1). In each plot, seedlings were planted in six rows, spaced 0.5 meters apart. Each row contained seven seedlings, with a distance of 1.0 meter between them, resulting in a total of 42 plants per plot (Figure 2). This experimental design also ensures that cultivar effects were not confounded by any variations in soil conditions.

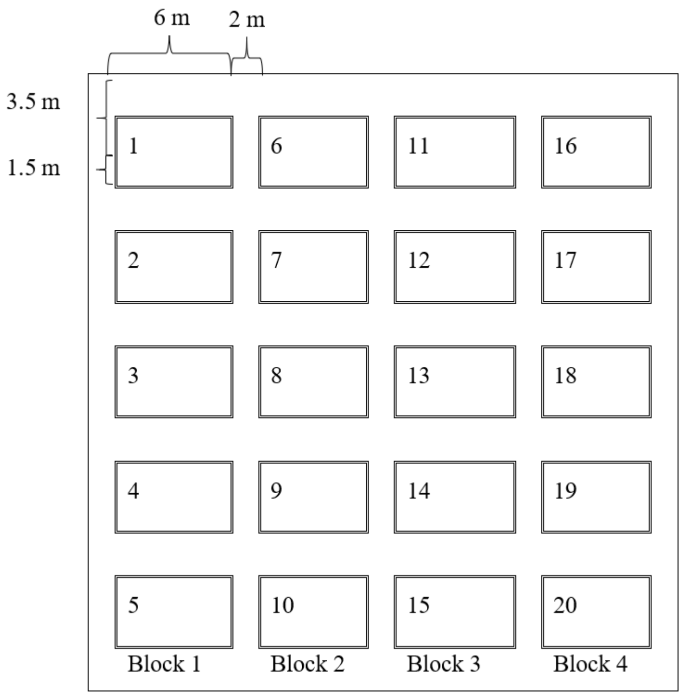

Figure 1: Experimental design.

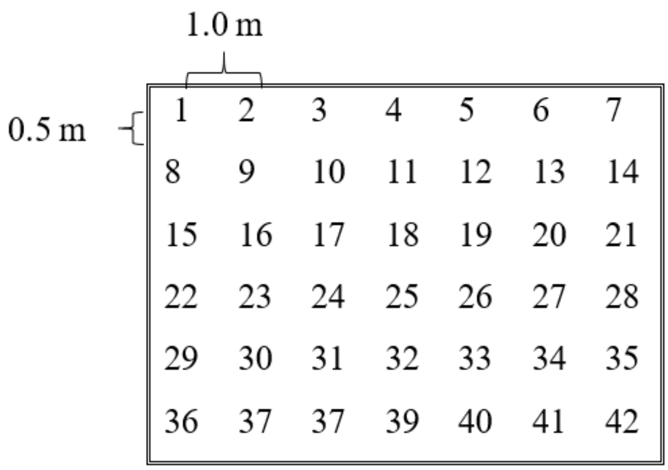

Figure 2: The number and distance of seedlings in each plot.

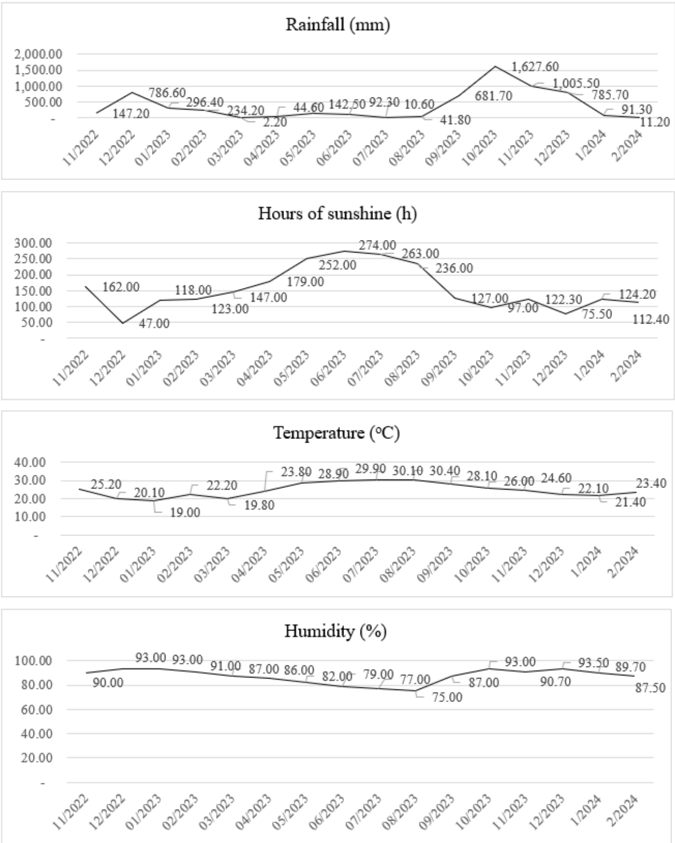

Figure 3: Rainfall, hours of sunshine, temperature, and humidity of the experimental months.
Source: Meteorological Station of Hue, Vietnam.

Seedlings were planted on February 1, 2023. The first harvest took place on August 1, 2023, and the second harvest was conducted on February 1, 2024. The cultivars were cut at a height of 60 centimeters above the ground. Leucaena is a woody perennial plant with a relatively long growth cycle. Therefore, a 6-month harvesting interval was selected to accommodate its growth characteristics and allow for substantial biomass accumulation. Additionally, this interval was designed to capture seasonal variation, with one harvest occurring during the dry season (March to August) and the other during the rainy season (September to February). This approach allowed us to assess the influence of seasonal climatic conditions on biomass yield and the availability of forage for animal feeding.

Plant measurements

Within each plot, five plants were selected for sampling using a systematic randomization procedure to ensure unbiased representation. Specifically, one plant was selected from each of the four corners of the plot excluding border plants and one from the center. The selection within each designated area was performed randomly by choosing the plant closest to a predetermined coordinate point marked during plot layout. This approach minimized edge effects and ensured consistent, unbiased sampling across all plots. The following measurements were taken on plant height, stem diameter, number of monthly branches, and foliage biomass, all assessed after six months of harvesting intervals. Plant height (in centimeters) was determined from the ground to the tip of the main stem. The stem diameter was measured at a height of 50 cm from the ground using a Panme caliper. The number of branches was determined by counting the total number of branches on the plant.

Biomass yield

Forage biomass yield was calculated from four inner rows, which included 20 plants out of a total of 42 plants in each plot. The plants were harvested at a height of 60 cm above the ground, and the fresh biomass yield of these 20 plants was weighed.

Chemical analysis

Additionally, a 1,000-gram sample of foliage from each plot was randomly collected. This sample was separated into leaves and stems, weighed and then dried in an oven at 60 °C for 72 hours before being weighed again. The leaf portions were crushed through a 1 mm sieve, placed in jars, and stored in a refrigerator at minus 20 °C for subsequent chemical analysis. Chemical analysis of the samples was conducted to measure dry matter (DM), crude protein (CP), ether extract (EE), and total ash according to AOAC (1990). Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were analyzed using the method described by Van Soest *et al.* (1991). These works were undertaken in the laboratory of the Faculty of Animal Husbandry and Veterinary Medicine at the University of Agriculture and Forestry, Hue University, Vietnam.

In vitro digestibility

The *in vitro* digestibility procedure was conducted at the laboratory of the Faculty of Agriculture of Kasetsart University following the ANKOM DaisyII Incubator protocol with specific details to ensure replicability. Approximately 0.5 g of dried and ground sample (1 mm screen) was weighed into ANKOM F57 filter bags, which were heat-sealed and pre-rinsed. Bags were incubated in the DaisyII Incubator at 39°C for 48 hours in buffered rumen fluid (Goering and Van Soest, 1970) under anaerobic conditions. Four replicate bags were used per sample, along with two blank bags for blank correction. After incubation, the bags were rinsed with cold water, dried at 60°C for 48 hours, and weighed to determine residue. Digestibility was calculated based on weight loss after incubation, corrected for blank values. The digestibility was calculated as follows:

In-vitro as-fed digestibility (IVAFD):

$$\text{IVAFD (\%)} = 100 - ((W_3 - (W_1 \times C_1)) / W_2 \times 100$$

Where; W_1 = Initial weight of the empty nylon bag; C_1 =

Blank bag correction factor (final weight of blank empty bag after incubation/initial weight of blank empty bag); W_2 = Net fresh weight of the feed sample; W_3 = Final weight of nylon bag after 48-hour incubation and drying.

In-Vitro Neutral Detergent Fiber Digestibility (IVNDFD):

$$\text{IVNDFD (\%)} = 100 - (\text{NDF residue after 48 h incubation} \times 100 / \text{NDF before incubation})$$

In-Vitro Acid Detergent Fiber Digestibility (IVADFD):

$$\text{IVADFD (\%)} = 100 - (\text{ADF residue after 48 h incubation} \times 100 / \text{ADF before incubation})$$

Animal ethics approval

All procedures involving animals in this study complied with the regulations on animal welfare and ethical standards for research in Vietnam and were approved by the Animal Ethics Committee of Hue University, under permit number HUVN0055, issued on 20 February 2025.

Data processing

The data were statistically analyzed by ANOVA through the Generalized Linear Model (GLM) in Minitab Version 16.2 (2010). Statistical assumptions for ANOVA were assessed prior to analysis. The normality of distribution was tested using the Shapiro–Wilk test, and the homogeneity of variances was evaluated using Levene's test in Minitab. The results indicated that both assumptions were satisfied, which justified the use of ANOVA via the GLM. Mean values (M) and the standard deviation of the mean (SEM) were calculated. Differences between the average values were analyzed by Tukey's test with a 95% confidence interval.

The experimental statistical model used is as follows:

$$Y_{ij} = \mu + T_i + B_j + e_{ij}$$

Where Y_{ij} represents the value of the dependent variable; μ is the overall mean value; T_i indicates the effect of the cultivar (i = 1-5); B_j denotes the effect of the block (j = 1-4); and e_{ij} is the random error of the experiment.

RESULTS

Plant height and stem diameter

The heights of five leucaena cultivars in the first and second harvests are presented in Table 2. In the first harvest, there were no significant differences in the heights of the five leucaena cultivars during the first four months after transplanting ($p > 0.05$). However, from the fifth month onwards, differences emerged ($p < 0.05$). The heights of the Tarramba, Peru and KU56 cultivars were greater than those of the Cunningham and KU15 cultivars. In the second harvest, growth performance varied among the cultivars starting two months after harvesting ($p < 0.05$). The Tarramba and KU56 cultivars displayed greater heights compared to the Peru and Cunningham cultivars.

During the first four months after transplanting, there was no difference in stem diameter among the five leucaena cultivars at a height of 50 cm from the ground ($p > 0.05$). However, differences in stem diameter among the cultivars became apparent at five and six months after transplanting ($p < 0.05$) (Table 3). In the second harvest, stem diameters varied among cultivars at all months of growth ($p < 0.05$), with KU56 and Tarramba exhibiting the largest diameters of 21.71 mm and 20.86 mm, respectively, after 12 months.

Table 2: Plant height of leucaena cultivars during the first and second harvests.

Harvest/month	Height (cm) of 5 leucaena cultivars by months					SEM	p value
	Tarramba	Peru	Cunningham	KU15	KU56		
First harvest (from 01/02/2023 to 01/08/2023)							
1 month (01/03/23)	22.0	21.1	19.9	20.6	20.0	0.81	0.349
2 months (01/04/23)	38.2	32.0	31.7	34.1	35.7	1.80	0.067
3 months (01/05/23)	86.4	80.7	71.9	75.5	89.4	5.23	0.111
4 months (01/06/23)	145.6	144.0	127.9	124.8	152.9	7.96	0.063
5 months (01/07/23)	202.0^{a}	192.0^{ab}	165.2^{bc}	156.4^{c}	194.9^{ab}	8.86	<0.001
6 months (01/08/23)	254.8^{a}	238.1^{ab}	199.9^{bc}	185.7^{c}	234.3^{ab}	10.5	<0.001
Second harvest (from 01/08/2023 to 01/02/2024)							
1 month (01/09/23)	125.5	135.9	124.8	122.8	133.3	4.18	0.119
2 months (01/10/23)	201.8^{a}	185.9^{ab}	176.9^{b}	177.1^{b}	199.9^{a}	5.77	0.003
3 months (01/11/23)	239.1^{a}	206.3^{b}	204.0^{b}	205.0^{b}	225.5^{ab}	6.55	<0.001
4 months (01/12/23)	258.9^{a}	216.1^{c}	216.5^{c}	222.6^{bc}	244.2^{ab}	6.46	<0.001
5 months (01/01/24)	285.4^{a}	238.2^{b}	248.9^{b}	247.2^{b}	276.7^{a}	6.61	<0.001
6 months (01/02/24)	302.4^{a}	256.3^{c}	270.2^{c}	272.4^{bc}	298.4^{ab}	7.04	<0.001

Values within row that have different letters (a, b, c) indicate significant differences ($p < 0.05$). Date format is dd/mm/yy.

Table 3: Stem diameter of leucaena cultivars by month during the first and second harvests.

Harvest/month	Stem diameter (mm) of 5 leucaena cultivars by months					SEM	p value
	Tarramba	Peru	Cunningham	KU15	KU56		
First harvest (from 01/02/2023 to 01/08/2023)							
1 month (01/03/23)	2.54[a]	2.20[ab]	1.76[b]	2.01[ab]	2.25[ab]	0.165	0.020
2 months (01/04/23)	3.97	3.67	3.42	3.46	3.59	0.197	0.296
3 months (01/05/23)	6.71	6.41	5.76	5.81	7.21	0.385	0.045
4 months (01/06/23)	10.15	10.52	9.32	8.72	10.73	0.566	0.072
5 months (01/07/23)	12.17[ab]	12.53[ab]	10.73[ab]	10.24[b]	12.78[a]	0.585	0.007
6 months (01/08/23)	14.19[ab]	14.34[ab]	11.90[bc]	11.32[c]	14.73[a]	0.675	0.001
Second harvest (from 01/08/2023 to 01/02/2024)							
1 month (01/09/23)	15.41[ab]	15.39[ab]	13.05[bc]	12.21[c]	15.99[a]	0.691	<0.001
2 months (01/10/23)	16.76[a]	16.64[ab]	13.93[bc]	13.41[c]	17.20[a]	0.701	<0.001
3 months (01/11/23)	18.17[a]	17.36[ab]	14.98[b]	14.75[b]	18.30[a]	0.729	<0.001
4 months (01/12/23)	19.03[a]	18.16[ab]	15.73[b]	16.00[b]	19.11[a]	0.759	0.002
5 months (01/01/24)	19.93[a]	19.00[ab]	16.84[b]	16.78[b]	20.41[a]	0.771	0.001
6 months (01/02/24)	20.86[ab]	19.78[abc]	18.07[bc]	17.62[c]	21.71[a]	0.782	0.001

Values within row that have different letters (a, b, c) indicate significant differences ($p < 0.05$). Date format is dd/mm/yy.

Table 4: Number of branches of each plant by month during the first and second harvests.

Harvest/month	Number of branches of 5 leucaena cultivars by month of 2 harvests					SEM	p value
	Tarramba	Peru	Cunningham	KU15	KU56		
First harvest (from 01/02/2023 to 01/08/2023)							
1 month (01/03/23)	1.75	1.65	0.75	1.10	1.20	0.272	0.066
2 months (01/04/23)	4.00	4.05	2.60	2.95	3.10	0.387	0.029
3 months (01/05/23)	5.65[ab]	6.10[a]	3.20[c]	3.95[bc]	3.95[bc]	0.472	<0.001
4 months (01/06/23)	7.95[b]	11.85[a]	4.35[c]	5.90[bc]	7.30[bc]	0.768	<0.001
5 months (01/07/23)	8.90[b]	14.05[a]	5.25[c]	6.65[bc]	8.30[bc]	0.811	<0.001
6 months (01/08/23)	9.90[b]	16.35[a]	6.20[c]	7.60[bc]	9.40[bc]	0.937	<0.001
Second harvest (from 01/08/2023 to 01/02/2024)							
1 month (01/09/23)	7.85[ab]	9.10[a]	6.30[b]	7.40[ab]	8.00[ab]	0.462	0.001
2 months (01/10/23)	13.00[ab]	14.40[a]	9.60[b]	10.65[ab]	12.70[ab]	1.19	0.040
3 months (01/11/23)	14.35	16.35	11.60	11.75	15.10	1.24	0.029
4 months (01/12/23)	15.90	17.20	12.45	12.85	16.60	1.33	0.033
5 months (01/01/24)	16.70	17.70	14.50	15.75	18.00	1.42	0.397
6 months (01/02/24)	17.75	19.00	15.95	17.40	19.55	1.29	0.313

Values within row that have different letters (a, b, c) indicate significant differences ($p < 0.05$). Date format is dd/mm/yy.

Number of branches and forage yield

The results presented in Table 4 indicate that, in the first harvest, the number of branches among the cultivars differed from 3 months to 6 months after transplanting ($p < 0.05$). The highest number of branches was found in Peru at 16.35 branches per plant. The lowest number of branches was found at Cunningham, with only 6.20 branches per plant. In the second harvest, there was no difference in the number of branches among the five cultivars ($p > 0.05$). The average number of branches per plant after 6 months ranged from 15.95 to 19.55 branches.

There were no significant differences in biomass yield of leaves, branches, and total forage among the five cultivars at the two harvests or throughout the year (Table 5; $p > 0.05$). The total forage yield was slightly higher for the Tarramba and KU56 cultivars, at 10,896 kg DM/ha/year and 9,129 kg DM/ha/year, respectively. The biomass yield for the cultivars at the second harvest was higher than that observed at the first harvest. The leaf ratios ranged from 46.90% to 49.93% of total forages, with no notable differences among the cultivars over the year.

Table 5: Total forage, leaf and stem yield (kg DM/ha) and leaf ratio (%) of five leucaena cultivars at two harvests in a year.

Harvest/forage parts	Leucaena cultivars					SEM	p value
	Tarramba	Peru	Cunningham	KU15	KU56		
First harvest (01/08/2023)							
Leaves	1,607	1,577	1,278	1,398	1,450	132	0.423
Stems	1,675	1,732	1,310	1,479	1,620	161	0.386
Total forage	3,281	3,309	2,587	2,877	3,070	281	0.375
Leaf ratio	48.94	48.08	49.35	48.61	46.97	1.38	0.774
Second harvest (01/02/2024)							
Leaves	3,662	2,409	2,832	2,876	3,006	559	0.630
Stems	3,953	2,742	2,798	2,992	3,053	459	0.375
Total forage	7,615	5,150	5,630	5,868	6,059	1,010	0.515
Leaf ratio	47.43	45.74	50.20	48.83	49.25	1.31	0.188
Whole year (2 harvests)							
Leaves	5,269	3,985	4,110	4,274	4,455	656	0.670
Stems	5,627	4,474	4,108	4,471	4,674	589	0.466
Total forage	10,896	8,459	8,217	8,745	9,129	1,236	0.577
Leaf ratio	49.93	46.90	49.90	48.84	48.54	0.91	0.255

Chemical composition

There were no significant differences in the chemical composition of CP, EE, NDF, ADF, and total ash in the leaf among the five cultivars (Table 6; p > 0.05). The CP content ranged from 233 g/kg of DM in the KU15 cultivar to 279 g/kg of DM in the KU56 cultivar. The NDF ranged from 330 g/kg of DM in the Tarramba cultivar to 365 g/kg of DM in the KU56 cultivar.

Table 6: Chemical composition of leaves (g/kgDM) of five leucaena cultivars.

Cultivars	Chemical composition				
	CP	EE	NDF	ADF	Total Ash
Tarramba	254	71	330	192	70
Peru	269	63	338	198	69
Cunningham	265	63	336	189	70
KU15	233	63	352	210	69
KU56	279	64	365	198	66

CP: Crude protein, EE: Ether extract, NDF: Neutral detergent fiber, ADF: Acid detergent fiber.

Table 7: *In vitro* digestibility (%) of leucaena leaves after 48-hour incubation using the DAISY^{II} incubator.

Leucaena leaves	IVTD (M ± SD)	IVNDFD (M ± SD)	INADFD (M ± SD)
Tarramba	51.77 ± 6.10	23.16 ± 5.36	13.69 ± 5.18
Peru	56.73 ± 0.13	39.16 ± 4.10	31.87 ± 6.20
Cunningham	51.22 ± 1.94	41.67 ± 6.04	35.57 ± 7.54
KU15	47.33 ± 0.23	35.97 ± 5.58	19.27 ± 8.06
KU56	55.03 ± 5.41	35.55 ± 4.02	27.98 ± 6.63

Values are means ± standard deviations (M ± SD). IVTD = *in vitro* true digestibility; IVNDFD = *in vitro* neutral detergent fiber digestibility; IVADFD = *in vitro* acid detergent fiber digestibility.

In vitro digestibility

The in vitro digestibility of leucaena leaves for IVTD ranged from 47.33% at KU15 to 56.73% at Peru, for IVNDFD from 23.16% at Tarramba to 41.67% at Cunningham and INADFD from 13.69% at Tarramba to 35.57% at Cunningham (Table 7). No statistical difference was observed in the in vitro digestibility of various leucaena cultivars (p > 0.05).

DISCUSSION

Leucaena cultivars have been primarily studied in many tropical countries for their potential to produce forages for ruminants, particularly in goat production. These cultivars also serve multiple purposes, including providing fuelwood for heating, creating green fencing, offering shade, and supplying materials for composting in home gardens. The purpose of our study is to evaluate the growth performance, biomass forage yield and chemical composition of forage to improve the quality of goat feeds in smallholder farms in Vietnam. Our analysis of five leucaena cultivars, as presented in Tables 2, 3 and 4, indicated that all cultivars had good growth performance under natural farming conditions. While there were differences in plant height and stem diameter, the number of branches remained consistent among the cultivars when harvested after six months. In the first and second harvests, Tarramba reached the greatest plant height of 254.8 cm and 302.4 cm, respectively. The lowest heights were found at KU15 in the first harvest at 185.7 cm, and at Peru in the second harvest at 256.3 cm (p < 0.05). A relatively similar trend in plant height and stem diameter was also found among five leucaena cultivars - Peru, Cunningham, Tarramba, KU19 and KU66 - planted in Thailand (Rengsirikul *et* *al*., 2011). At six months, the plant height varied from 275 cm for the Peru cultivar to 391 cm for Tarramba, indicating differences in height performance among the cultivars. Additionally, after six and twelve months, the stem diameters of the leucaena cultivars were found to be larger in Tarramba and KU66 and smaller in Peru and Cunningham. In our study, Tarramba demonstrated the largest stem diameters, measuring 14.19 cm at the first harvest and 20.68 cm at the second harvest. In contrast, KU15 showed the smallest diameters, with measurements of 11.32 cm and 17.61 cm, respectively ($p < 0.05$). While differences in branch number were noticeable at the first harvest, they were no longer evident at the second harvest. This change is likely attributed to the initial establishment vigor and slower branching in some cultivars. By the time of the second harvest, regrowth had equalized branch development, leading to fewer differences among the cultivars.

In our experiment, the biomass yield did not differ among the five cultivars studied ($p > 0.05$). The yields ranged from 8,217 kg DM/ha/year for the Cunningham cultivar to 10,896 kg DM/ha/year for the Tarramba cultivar. For the leaf part, the yields ranged from 3,985 kg DM /ha/year in Peru to 5,269 kg DM/ha/year in Tarramba. A study by Rengsirikul *et al*. (2011) on the Peru, Cunningham, Tarramba, KU19, and KU66 cultivars, planted in Thailand, showed that the leaf yields of these cultivars, cut at 50 cm above ground after one year, ranged from 1.68 tons DM/ha for Peru to 4.06 tons DM/ha for KU66. The biomass yield of branches varied from 1.71 tons DM/ha for Peru to 3.15 tons DM/ha for KU19 and KU66. Casanova-Lugo *et al*. (2014) conducted an experiment on *Leucaena leucocephala* in Mexico, which reported a biomass yield of edible forage harvested 1 meter above the ground with a cutting interval of three months, with four harvests a year. This approach yielded 3.5 tons DM/ha in the dry season and 3.4 tons DM/ha in the rainy season, for a total of 6.9 tons DM/ha/year. The three-month cutting interval (Casanova-Lugo *et al*., 2014) and the six-month interval used in our experiment may produce higher yields of edible forage from leucaena compared to a twelve-month interval, as suggested by Rengsirikul *et al*. (2011). Longer cutting intervals could allow for greater biomass accumulation and nutrient storage for the plants.

There were no differences in CP, EE, NDF, ADF and total ash content among the five cultivars in our experiment ($p > 0.05$). The leucaena cultivars demonstrated a high CP content, ranging from 23.3% in the KU15 cultivar to 27.9% in the KU56 cultivar; however, these differences were not statistically significant. This lack of significance may be attributed to the limited number of replications (only four per cultivar) used in the chemical analysis, which could have reduced the statistical power to detect variation among cultivars. The CP levels of these leucaena cultivars in our experiment align with the findings of Rengsirikul *et al*. (2011) in Thailand, Casanova-Lugo *et al*. (2014) and Hernández Hernández *et al*. (2020) in Mexico. Additionally, the NDF and ADF values of five leucaena cultivars - Peru, Cunningham, Tarramba, KU 19 and KU66 - studied in Thailand (Rengsirikul *et al*., 2011) showed no significant differences across the cultivars.

The *in vitro* digestibility (IVTD) of the leucaena cultivars examined in this study ranged from 47% to 57%. These values were lower than those previously reported for younger leucaena foliage, which were between 58% to 65% for plants harvested after 2 to 3 months of regrowth (Rengsirikul *et al*., 2011). The relatively low IVTD observed in this study can primarily be attributed to the longer cutting interval (six months), which allowed the plants to mature and accumulate more structural components. As leucaena stems and leaves mature, thickening of the cell walls increases the deposition of lignin and cellulose, thereby reducing the proportion of readily fermentable cell contents. This is consistent with the higher NDF and ADF levels observed, which are negatively correlated with digestibility. Another factor is lignin, which acts as a physical barrier limiting microbial access to cellulose and hemicellulose in the rumen. Even at moderate levels, lignin substantially reduces forage digestibility because lignified tissues cannot be digested by rumen microbes (Van-Soest *et al*., 1991). In leucaena, fiber fractions tend to increase with plant age, particularly during the dry season when growth is slower and tissues become more fibrous. This explains why digestibility values in the present study were lower than in studies using younger or more frequently harvested leucaena (Casanova-Lugo *et al*., 2014). Thus, the relatively low IVTD in our results reflects both the extended regrowth period and the seasonal influence on plant physiology. From a management perspective, reducing harvest intervals or combining leucaena with more digestible tropical grasses could help balance dietary fiber and improve overall rumen fermentation efficiency in goats.

One of the key anti-nutritional concerns when using *Leucaena leucocephala* as ruminant feed is the presence of mimosine, a toxic non-protein amino acid that can negatively affect animal performance. Mimosine is known to cause hair loss, reduced feed intake, and poor growth in ruminants when consumed in high quantities (Shelton and Dalzell, 2007; Dalzell *et al*., 2012). Phaikaew *et al*. (2012) also emphasized that the digestibility of leucaena can be further affected by secondary compounds such as mimosine and condensed tannins, which may inhibit rumen microbial activity. Although this study did not quantify mimosine levels in the tested cultivars, it is well-documented that mimosine content can vary among leucaena cultivars, with some lines such as Tarramba and Cunningham showing relatively lower toxicity risks due to better adaptation or lower mimosine concentrations (Jones, 1994; Nimbkar, 2019). To effectively manage mimosine toxicity, several mitigation strategies can be employed. One approach is the gradual adaptation of animals to leucaena-based diets, which allows for the establishment of *Synergistes jonesii*, a rumen bacterium that can degrade mimosine and its toxic derivatives (Allison *et al*., 1992). Additionally, inoculation with rumen fluid containing *Synergistes jonesii* from adapted animals has been proven to be an effective method in managing toxicity in native populations (Jones and Megarrity, 1986). The negative effects of mimosine can further be minimized through controlled inclusion rates, mixed feeding strategies, and harvesting at optimal stages to ensure safe nutrient profiles. Further studies are recommended to quantify mimosine levels in these cultivars under Vietnamese conditions and assess the presence and efficacy of mimosine-degrading microbes in local goat populations.

Despite their lower fiber digestibility, leucaena cultivars can be considered a rich-protein feed source, offering a valuable supplement when combined with digestible grasses. Incorporating leucaena can improve overall dietary protein intake and support microbial protein synthesis, as noted in several previous studies (Okoruwa, 2020; Takawale *et al*., 2016). However, it is important to acknowledge that the results presented in this study are limited to the establishment year of the *Leucaena leucocephala* cultivars. Forage yield, nutritive value, and plant persistence can vary significantly across years due to climatic fluctuations, pest and disease pressure, and plant maturity dynamics (Shelton and Brewbaker, 1994). As such, findings from a single year may not fully reflect the long-term agronomic performance or sustainability of each cultivar. To obtain a more comprehensive understanding of their suitability under local conditions, multi-year field trials are recommended. These should assess year-to-year variations in dry matter yield, crude protein content, and stand survival, particularly under varying harvesting regimes and environmental stresses. Long-term data will be essential for making reliable recommendations to smallholder farmers regarding cultivar selection and pasture management strategies.

CONCLUSIONS

This study evaluated five *Leucaena leucocephala* cultivars for their growth, forage yield, and nutritive value under the conditions of Central Vietnam. All cultivars adapted well; however, significant differences were observed in plant height and stem diameter. The Tarramba and KU56 cultivars consistently outperformed the others, showing superior growth performance and slightly higher forage yields. Although the number of branches varied early, it became similar among cultivars after six months.

No significant differences were found in forage yield or chemical composition, with crude protein levels ranging from 23% to 28% DM, confirming leucaena as a valuable protein supplement to tropical grasses. The in vitro digestibility values were lower than those reported in earlier studies, likely due to longer cutting intervals.

Overall, Tarramba and KU56 appear to be the most promising cultivars for improving goat nutrition in smallholder systems. However, long-term, multi-year studies are needed to confirm their persistence, yield stability, and nutritional quality under diverse environmental and management conditions.

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NOVELTY STATEMENT

This study provides the first evaluation of five *Leucaena leucocephala* cultivars under Hue, Vietnam conditions. All cultivars adapted well, with Tarramba and KU56 showing superior growth and forage yield compared with Peru, Cunningham, and KU15. Despite similar chemical composition among cultivars, all had high crude protein content. The results demonstrate that Leucaena can serve as a valuable high-protein forage option to improve goat nutrition in smallholder farming systems in Vietnam.

AUTHOR’S CONTRIBUTION

Liem TN, Dung NM and Duc LM conducted the field agronomy experiments and goat feeding trials. Hai DT and Tam VTM performed the chemical analyses at Hue University, and Chotchutima S and Boonsaen P carried out the in vitro analyses at Kasetsart University. Anh LTQ and An LV analysed the data and drafted the manuscript. All authors read and approved the final version of the manuscript.

Generative AI and AI-assisted technology statement

We did not use AI technology for the current research, except Grammarly for Grammar and spell check.

Conflict of interest

The authors have declared no conflict of interest.

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